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14. ABSTRACT
This project is to request equipment funding for a novel parallel, high speed, large scale nano-manufacturing instrument. The key element of the instrument is a nanoscale optical antenna capable of producing a nanometer size light spot, which has been demonstrated in the PI's laboratory. With the use of an array of nanoscale optical antenna to produce a large number of nanometer size laser beams, a large number of patterns can be fabricated simultaneously, or a complex pattern with nanometer size features can be fabricated over a large area. We have acquired the necessary equipment and has built the instrument. Current research is focused on testing the instrument for papallel nano-manufacturing.

15. SUBJECT TERMS
Nano-manufacturing, nanoscale optical antenna

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Final Technical Report

Project Title: Equipment for Parallel, High Speed Nano-manufacturing

ONR Award No.: N00014-04-1-0808

PI: Prof. Xianfan Xu, School of Mechanical Engineering, Purdue University

Project Area Definition: Nano-manufacturing, (unconventional, alternative) nano-lithography, nano-optics

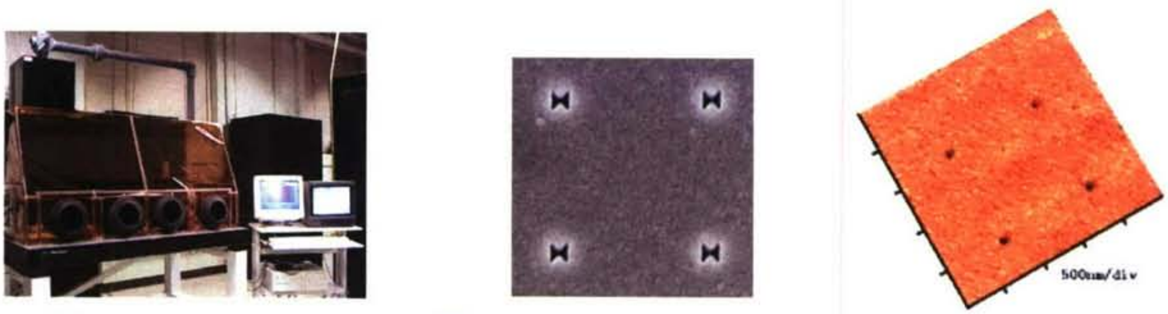
Objectives: To develop an optical based massively parallel nano-manufacturing technique.

Approach: The enabling technology in the proposed nano-manufacturing system is a nanoscale optical antenna capable of concentrating light into a nanometer size domain with high transmissivity. The concentrated radiation (light spot) from the antenna will then be used for nano-manufacturing. We use an array of antennas, each to be individually controlled, for parallel nano-manufacturing and nano-lithography.

Accomplishments: (a) Constructed a parallel nano-manufacturing/lithography apparatus, which is housed in a table-top class 10 glove box as shown in Fig. 1a. (b) Developed fabrication technologies for making antenna arrays as shown in Fig. 1b and demonstrated their light concentration capability and potentials for nano-lithography as shown in Fig. 1c. (c) Developed another key component of the apparatus, a compliant kinematic flexure system for maintaining contact for lithography during scanning of the antenna array over the sample surface as shown in Fig. 2a. (d) Investigated fundamentals of light concentration and enhancement in the antenna array, including the development of a femtosecond resolved spectral near field scanning optical microscope (Fig. 2b). Five journal articles, ten invited talks and a number of conference presentations result from this work and are listed in the publication list.

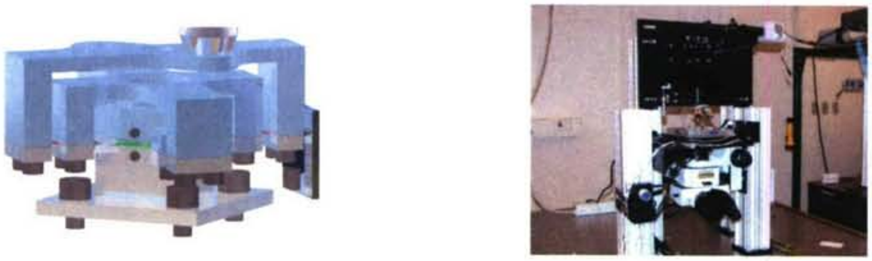
Performance Improvements: Utilizing nano-antennas for lithography is a novel concept first proposed in this project. It was intended to provide an alternative, low cost lithography method to those currently being used/investigated elsewhere such as EUV lithography. It is estimated that this technology will be able to produce nanoscale patterns with resolution better than 50 nm, at a cost only a fraction of other technologies (~ $100k vs. >>$M). It is anticipated that tens to hundreds of nanoscale light spots can be used in parallel to produce complex patterns in parallel. Being able to concentrate light into nano domain will also have applications in data storage, inspect, and ultra-high resolution bio-sensing.

Project Task Description & Breakout by $/YR: The project task is to construct the nanolithography apparatus. The budget ($168 k) is for equipment only.



(a) (b)
(c)

Figure 1. (a) A nano-lithography system housed in a class 10 glove box. (b) Bowtie antenna array fabricated suing focused ion beam milling. (c) Nanometer hole arrays produced by bowtie array in (b).



(a) (b)

Figure 2. (a) A kinematic flexure system for maintaining contact between antenna arrays and photoresist. (b) A home-built femtosecond resolved spectral nanoscale scanning optical microscope.

List of Publications:

Journal articles:

1. Jin, E.X., and Xu, X., 2004, "FDTD Studies on Optical Transmission through Planar Nano-Apertures in a Metal Film," J. Journal Applied Phys., Vol. 43, pp. 407 - 417.
2. Jin, E.X., and Xu, X., 2005, "Radiation Transfer through Shaped Nanoscale Apertures," J. of Quantitative Spectroscopy and Radiative Transfer, Vol. 93, pp. 163 – 173.
3. Jin, E.X., and Xu, X., 2005, "Obtaining super resolution light spot using surface plasmon assisted sharp ridge nano-aperture," Appl. Phys. Lett. Vol. 86, pp.111106-08. Also selected for publication in the March 21, 2005 issue of Virtual Journal of Nanoscale Science & Technology.
4. Xu, X., Jin, E.J., Uppuluri, S.M., Wang, L., 2005, "Concentrating Light into Nanometer Domain using Nanoscale Ridge Apertures and Its Application in Laser-based Nanomanufacturing," J. Phys. D., in press.
5. Wang, L., Sreemanth, U.M.V., Jin, E.X., and Xu, X., 2006, "Nanolithography using high transmission nanoscale ridge apertures, Nanoletters, Vol. 6, pp. 361-364.
6. Jin, E.X., and Xu, X., 2006, Enhanced optical near field from a bowtie aperture," Appl. Phys. Lett. Vol. 88, pp. 153110 – 153112. Also selected for the April 24, 2006 issue of Virtual Journal of Nanoscale Science & Technology.

Invited presentations:

1. "Enhancement of Optical Transmission through Planar Nano-Apertures in a Metal Film," July 2004, SPIE Nanofabrication Conference, Denver, CO.
2. "Laser based Micro and Nano Engineering," October 2004, Symposium on Micro- and Nanoscale Laser Materials Processing, 41st Annual Technical Meeting of the Society of Engineering Science, Lincoln, NE.
3. "Thermal Aspects in Laser-based Micro and Nanoscale Materials Processing and Manufacturing," November 2004, panel discussion on "Challenges and Opportunities in Materials Processing and Manufacturing," IMECE2004, Anaheim, CA.
4. "Optical-based Parallel Nano-manufacturing," November 2004, panel discussion on "Nano-manufacturing," IMECE 2004, Anaheim, CA.
5. "Optical-based Micro and Nano-engineering," March 2005, University of Kentucky Nanoscale Engineering Certificate Program.
6. "Concentrating Light into Nanometer Domain using Nanoscale Ridged Apertures and Its Application in Laser-based Nanomanufacturing," September 2005, Conference on Laser Ablation (COLA), Banff, CA.
7. "Laser-based Micro- and Nano-fabrication," October 2005, SPIE Optics East 2005, Boston, MA.
8. "Radiative Transfer through Nanoscale Optical Apertures," November 2005, panel discussion on " Challenges and Opportunities in Materials Processing and Manufacturing," IMECE 2005, Orlando, FL.
9. "Design, fabrication, and characterization of nanometer-scale ridged aperture optical antenna," January 2006, SPIE Photonics East 2006, San Jose, CA.
10. "Laser Micro and Nano Engineering," February 2006, Department of Mechanical Engineering, Florida Institute of Technology.
11. "Laser Micro and Nano Engineering," April 2006, Seagate Technology, Pittsburg, PA.
12. "Nano-lithography using Optical Antenna," June 2006, SPIE Photonics North, Quabec City, Canada

13. "Nano-lithography using Ridge Apertures," International Workshop on Plasmonics and Applications for Nanotechnologies, December 2006, Singapore.

Other conference presentations and publications:

1. Jin, E.X., Uppuluri, S.M.V., and Xu, X., 2004, "Enhancement of optical transmission through planar nano-apertures in a metal film," Gordon Research Conference on Laser Interactions with Materials, Andover, NH.
2. Jin, E.X., and Uppuluri, S.M.V., and Xu, X., 2004, "Field Concentration using Nanoscale Ridge Apertures," Symposium on Micro- and Nanoscale Laser Materials Processing, 41st Annual Technical Meeting of the Society of Engineering Science, Lincoln, NE.
3. Uppuluri, S.M.V., Jin, E.X., and Xu, X., 2004, "Nanoscale Antenna Structures for Field Enhancement and their NSOM Characterization," presented at the MRS Meeting, Boston, MA.
4. S. M. Uppuluri, E. X. Jin, and X. Xu, 2005, "Nanomanufacturing using High Transmission Nanoscale Ridge Apertures," IMECE 2005-79918.
5. Jin, E.X., and Xu, X., 2003, "Enhancement of Optical Transmission through Planar Nano-Apertures in a Metal Film," Proceedings of IMECE 2003, Paper No. IMECE-55235 (CD ROM).
6. Jin, E.X., and Xu, X., 2004, "Radiation Transfer through Shaped Nanoscale Apertures," in Proceedings of Radiation IV, Paper #42 (CD ROM).
7. Uppuluri, S.M.V., Jin, X.J., and Xu, X., 2004, "Nanolithography using Nanoscale Ridge Apertures," Nano-04 - ASME Integrated Nanosystems.
8. E.X. Jin and X. Xu, 2005, "Measurement of Radiation through Nanoapertures using Near Field Scanning Optical Microscopy," IMECE 2005-83059.
9. Xu, X., Wang, L., Uppuluri, S.M., and Jin, E.X., 2006, "Nanolithography using High Transmission Nanoscale Ridge Apertures," to be presented at the 7th International Symposium on Laser Precision Microfabrication, Kyoto, Japan, May 2006.
10. Wang, L., Uppuluri, S.M., Jin, E.X., and Xu, X., 2006, "Contact Optical Nanolithography using Nanoscale Apertures," to be presented at the 2006 NSF Grantees' conference, St. Louis, MO, and published in conference CD proceedings.